

Limb Corrections and Channel Adjustments for Red-Green-Blue Composites from Geostationary Satellites

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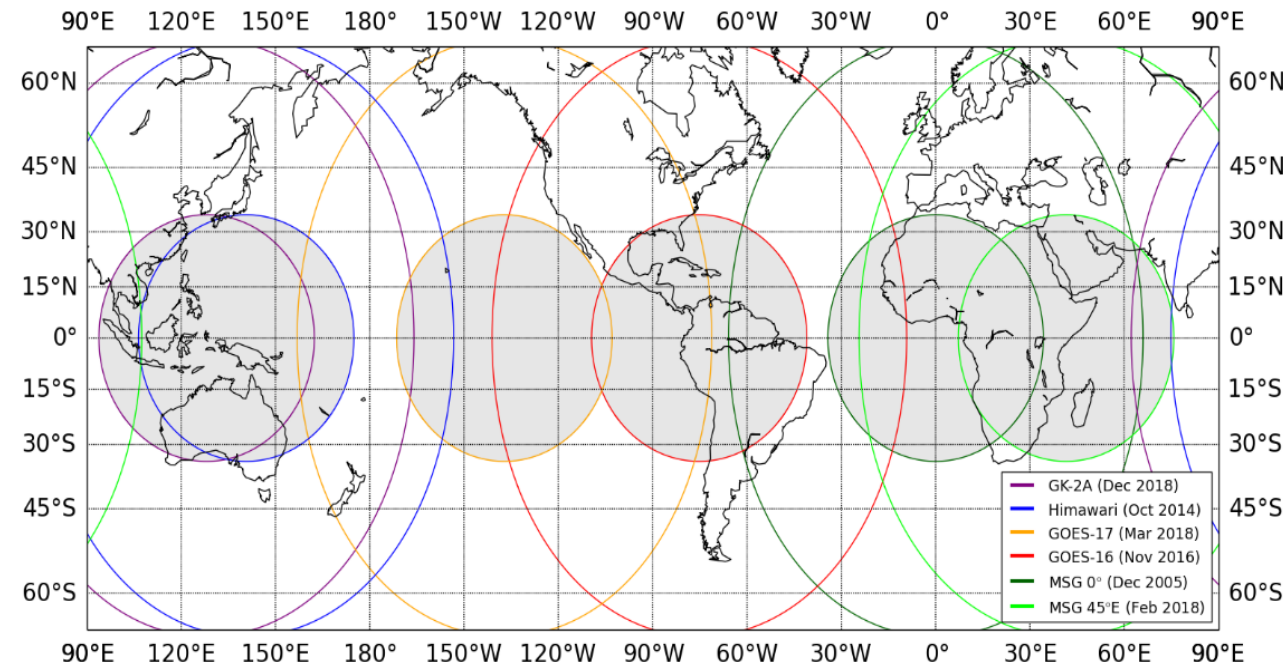
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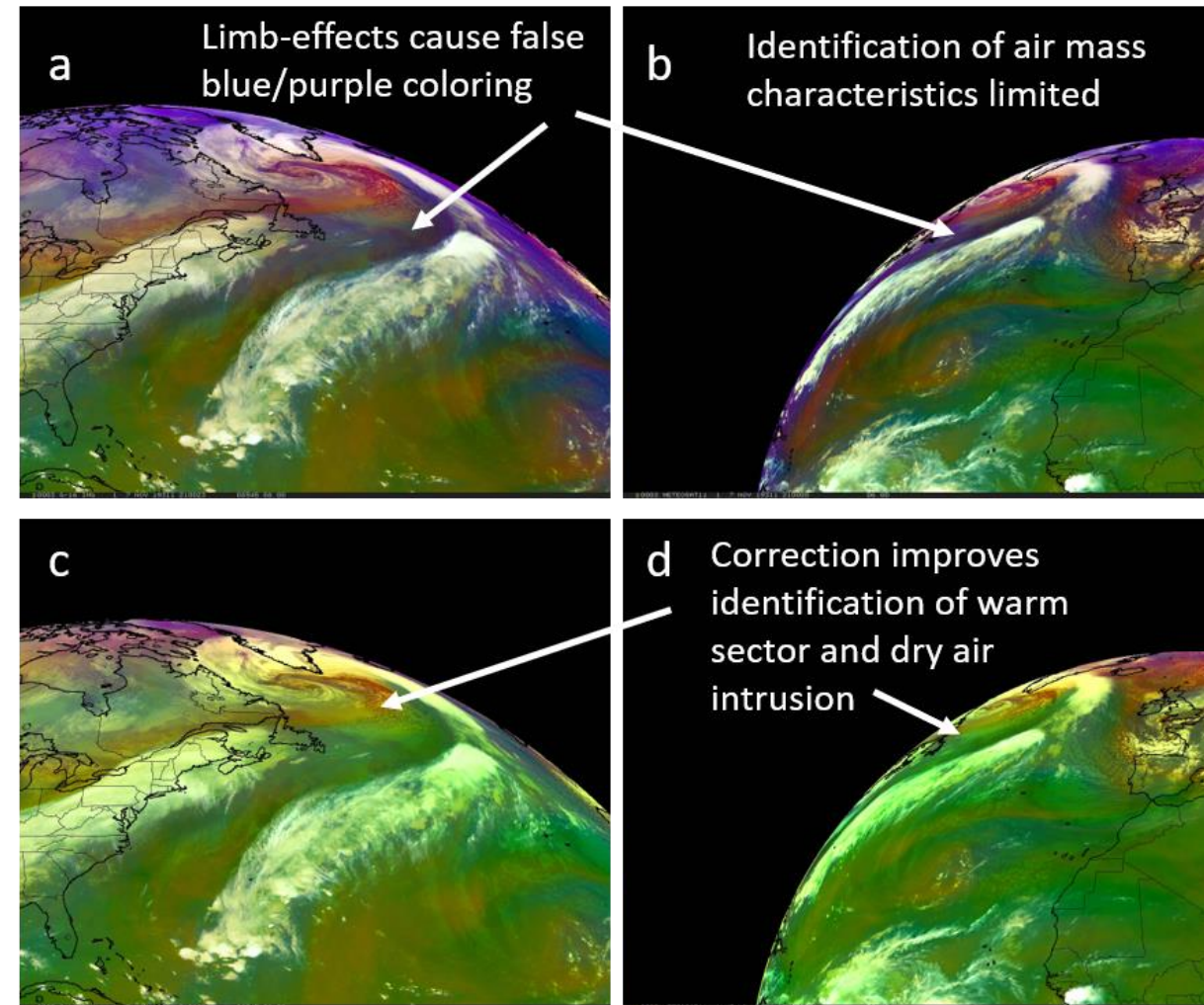
- Use of Red-Green-Blue or RGB composite imagery derived from combinations of multispectral imagery have become popular to monitor dust, fog, cloud characteristics, air mass structure, and surface features with time.
- Geostationary satellite imagery allows these products to be used to track features over long distances and study the processes that contribute to the development of fast evolving features.
- However, the use of RGB imagery on a regional and global basis is not without limitations due to the impact of limb-effects at high viewing angles and subtle spectral channel differences between satellite sensors.



Coverage/overlapping regions of current geostationary satellites. Shaded regions indicate viewing zenith angles $< 40^\circ$ where limb effects are minimal, whereas the unshaded regions indicate viewing zenith angles of 40° – 75° where limb effects are significant and degrade the utility of the products.



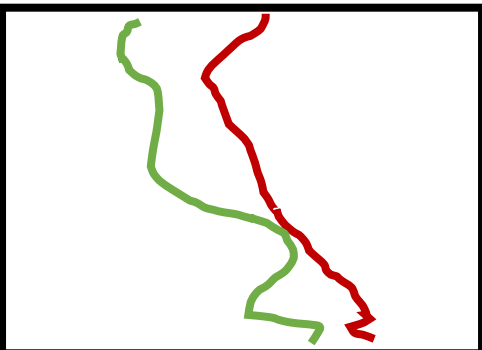
- The increased absorption path length at off nadir scan angles produces limb cooling in the infrared absorption channels
- At high viewing angles, the upwelling radiation passes through a larger column of the atmosphere before reaching the satellite, a greater amount of upwelling radiation is absorbed, and cooler brightness temperatures are observed
- Brightness temperatures can be 4-12 K cooler at high-viewing angles in the single channel imagery and can produce erroneous color changes in the RGB products, impacting the coloring and interpretation of RGB imagery at high viewing angles.



7 Nov. 2019 2100 UTC Air Mass RGB (a) GOES-16, (b) SEVIRI, (c) GOES-16 limb-corrected, (d) SEVIRI limb-corrected



Collected global model atmospheric profiles



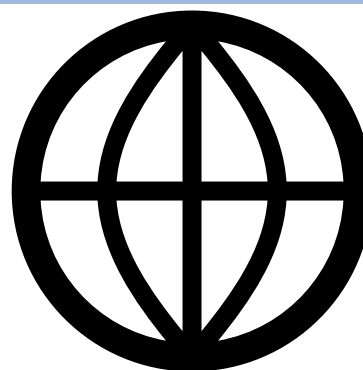
- 4-years of ECMWF ERA5 profiles
- <1 % total cloud cover threshold
- Randomly selected with even global and seasonal coverage

Modeled top of atmosphere brightness temperatures



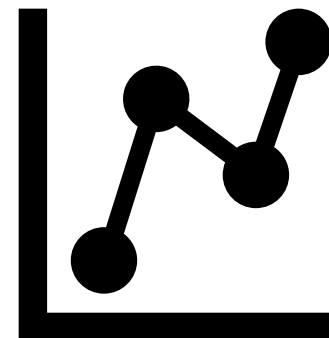
- Infrared channels for viewing zenith angles 0-80° at 5° intervals
- Simulations for each geostationary sensor

Binned brightness temperatures



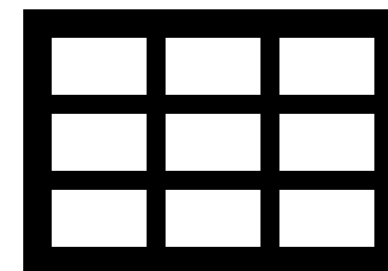
- Defined bins by 15° latitude intervals and month
- Linear best fit was determined for each bin based on the limb-correction equation

Determined statistical relationships



- Second order polynomial best fit for VZA < 60°
- First-order linear best fit for VZA > 60°
- Results in 4 best fit coefficients

Final look-up tables of limb-correction coefficients

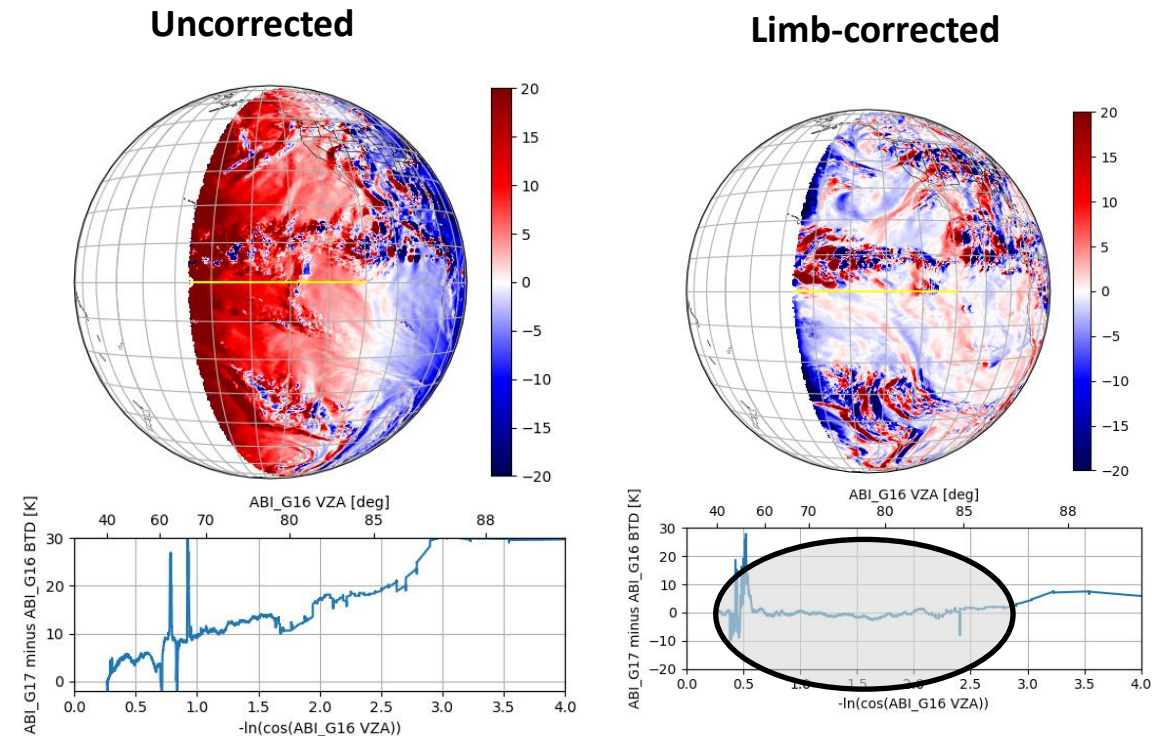


- Coefficients fit to a continuous ninth-order polynomial surface
- The polynomial surface coefficients stored in look-up tables

$$\text{For } 0 - 60^\circ: T_{\theta_z} - T_0 = C_2 |\ln(\cos \theta_z)|^2 + C_1 |\ln(\cos \theta_z)|$$

$$\text{For } 60 - 80^\circ: T_{\theta_z} - T_0 = C_2 |\ln(\cos \theta_z)| + C_1$$

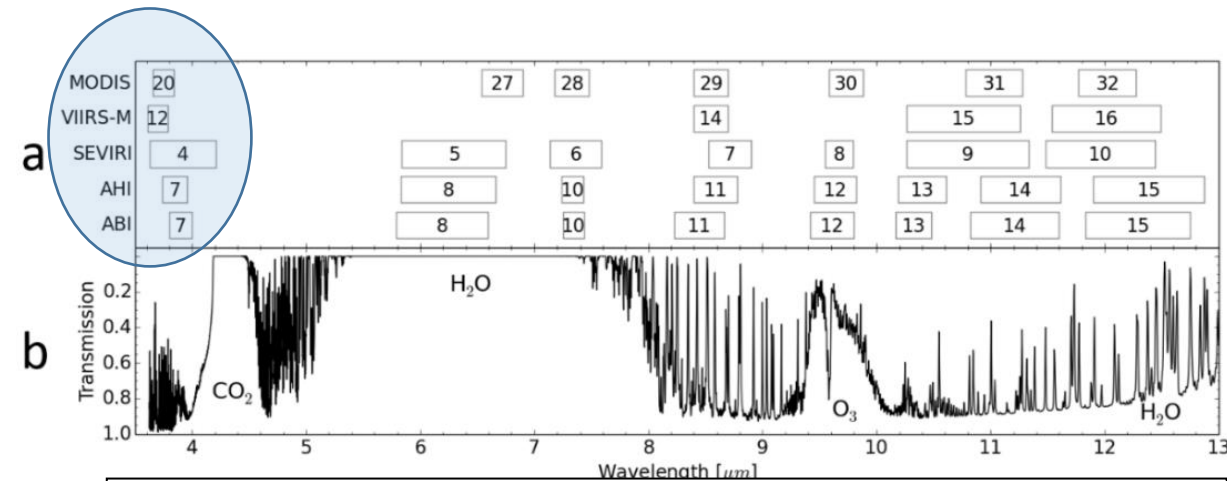
- Validation was performed through comparison of satellite imagery at collocated pixels
- Reduces the impact of limb effects from over 30K to less than 5K at $\sim 87^\circ$ viewing zenith angle as shown in the $7.3\text{ }\mu\text{m}$ water vapor band
- Limb correction reduces limb effects at 85° viewing zenith angle by 10-20 K for all bands (3.9 to $13.3\text{ }\mu\text{m}$).



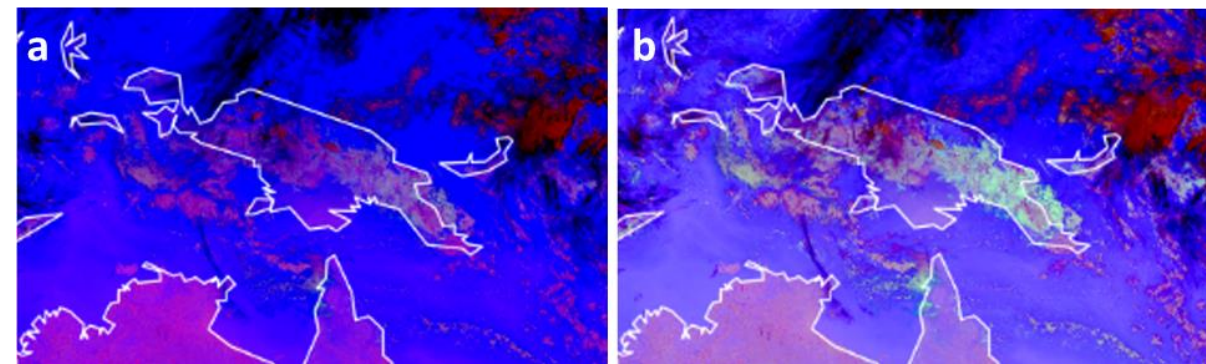
7.3 μm water vapor band GOES-17 (near-nadir) minus GOES-16 (limb) Brightness Temperature Difference [graph corresponds to data along yellow line from east to west]



- Spectral differences between sensors on the various polar and geostationary satellites (qualitatively shown in the diagram on the right) can cause color variations in the RGB products, preventing proper interpretation and use of these products for global studies.
- These spectral differences can be accounted for through the intercalibration of single channel imagery between the various satellites or with an adjustment of the RGB recipes so that the RGB products match for the various satellites.
- Recipe adjustments applied to Himawari AHI imagery on the right shows an enhancement of cloud features consistent with the expectations of the night-time microphysics RGB product.



(a) Comparison of sensor bands used to produce common RGB composites. Band numbers are indicated inside each box with the box width representing the spectral bandwidth (full width at half maximum). (b) Atmospheric transmission spectrum derived from the Infrared Atmospheric Sounding Interferometer (IASI) within CRTM (Han et al. 2006) using the CRTM U.S. Standard Atmosphere climatology definition.



5 Aug. 2015 1600 UTC Himawari-8 AHI Night-time Microphysics RGB (a) standard EUMETSAT RGB recipe applied Red: -4 to 2 K, Green: 0 to 10 K, and Blue: 243 to 293 K and (b) recipe adjustment applied Red: -7 to 2 K, Green: -2 to 6 K, and Blue: 244 to 292 K for intercalibration.

Intercalibrate a Proxy Reference Sensor

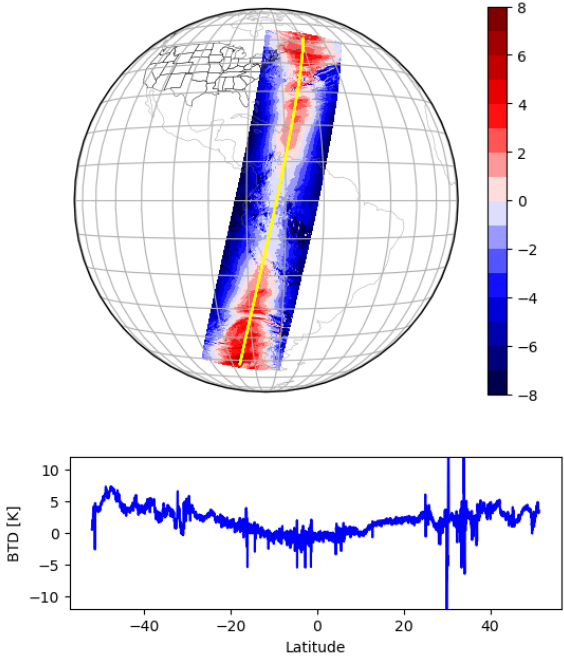
- 12 case studies of near-nadir (0-10°S), mostly clear ocean scenes
- Transect of shared points analyzed through linear regression to calculate the average monthly brightness temperature offset
- Channel-specific offset applied to Aqua MODIS

MODIS		Meteosat SEVIRI		Tb Offset
20	3.75	4	3.90	-2.96
27	6.72	5	6.25	-3.09
28	7.33	6	7.35	0.40
29	8.55	7	8.70	-0.10
30	9.73	8	9.66	-1.74
31	11.03	9	10.80	0.70
32	12.02	10	12.00	-0.41
33	13.34	11	13.40	-1.24

Compare each Geostationary Sensor to the Proxy Reference Sensor

- 12 case studies of cloud-cleared scenes
- Transect of shared points (40° N – 40°S) between the Proxy and geostationary sensors for single channels and band differences important to the suite of RGBs

6.2
10.3
6.2-7.3
9.7-10.8
10.3-3.9
10.3-8.6
11.2-8.6
12.4-10.3



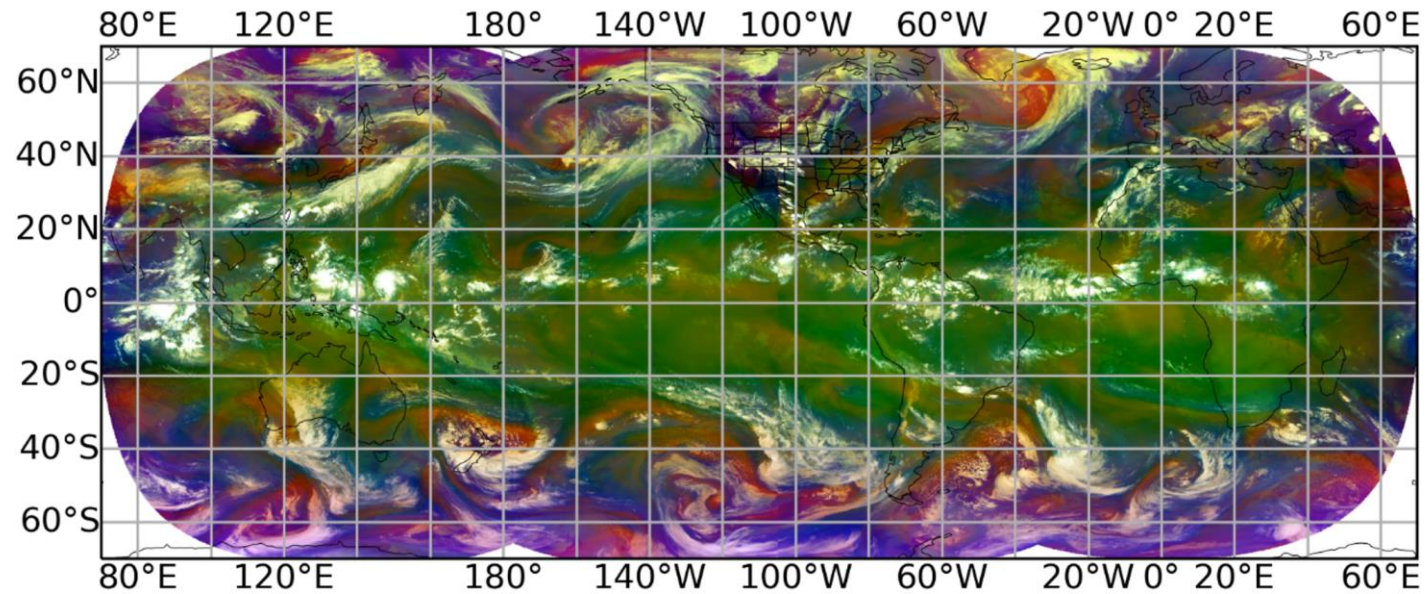
Statistical analysis to determine new RGB recipes

- Scatter plots and resulting linear regression equation averaged for 12 case studies to account for seasonal variation
- Linear regression equations $y = mx + b$ applied to original SEVIRI recipes to arrive at the proper intercalibrated-recipe
- Sensor-specific refined recipes for Air Mass, Dust, Night-time Microphysics, 24-hr Microphysics, and Ash RGBs

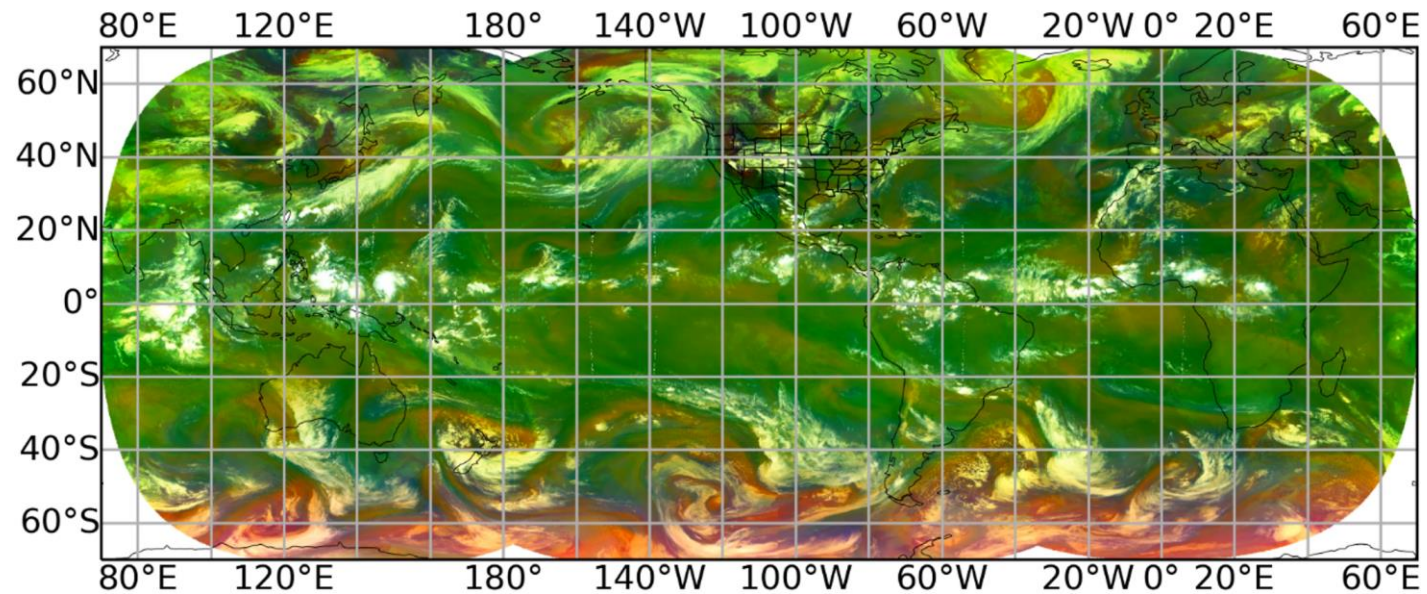
Air Mass	Band or Band Difference	MSG SEVIRI Min	MSG SEVIRI Max	GOES-16 ABI Min	GOES-16 ABI Max	Gamma
Red	6.2-7.3	-25	0	-24.6	0.1	1
Green	9.7-10.8	-40	5	-43.6	3.2	1
Blue	6.2 (inverted)	243	208	242.5	209.5	1

Air Mass RGB

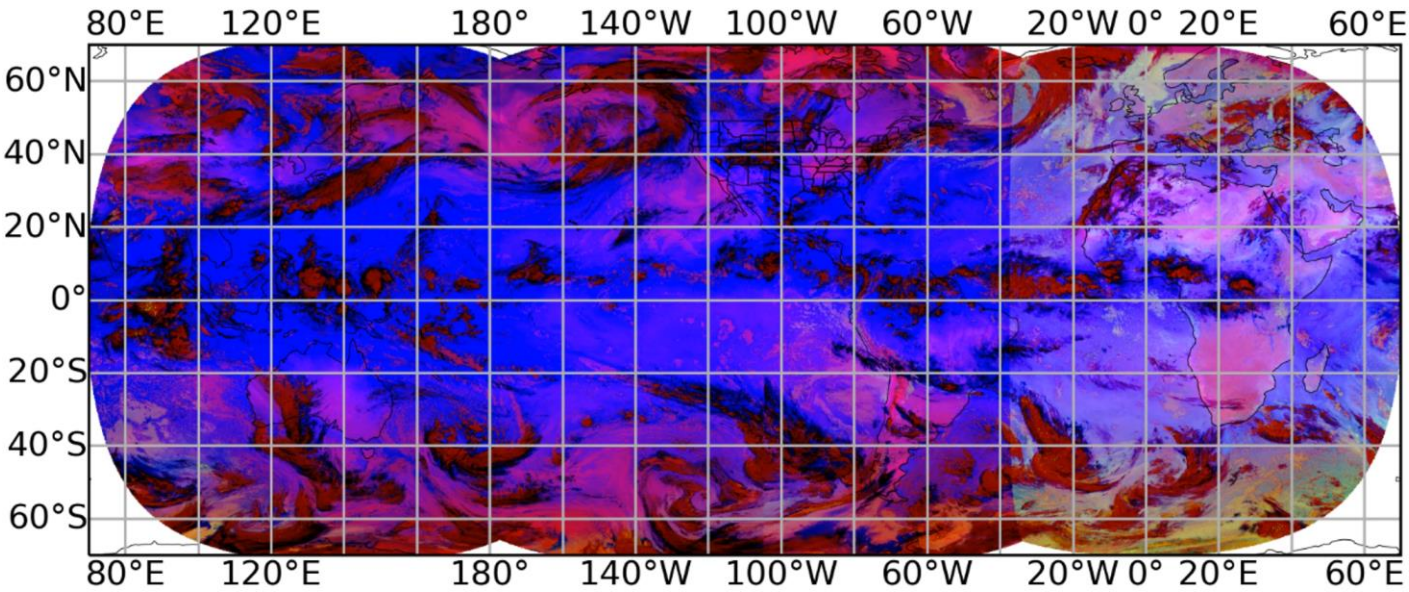
Uncorrected



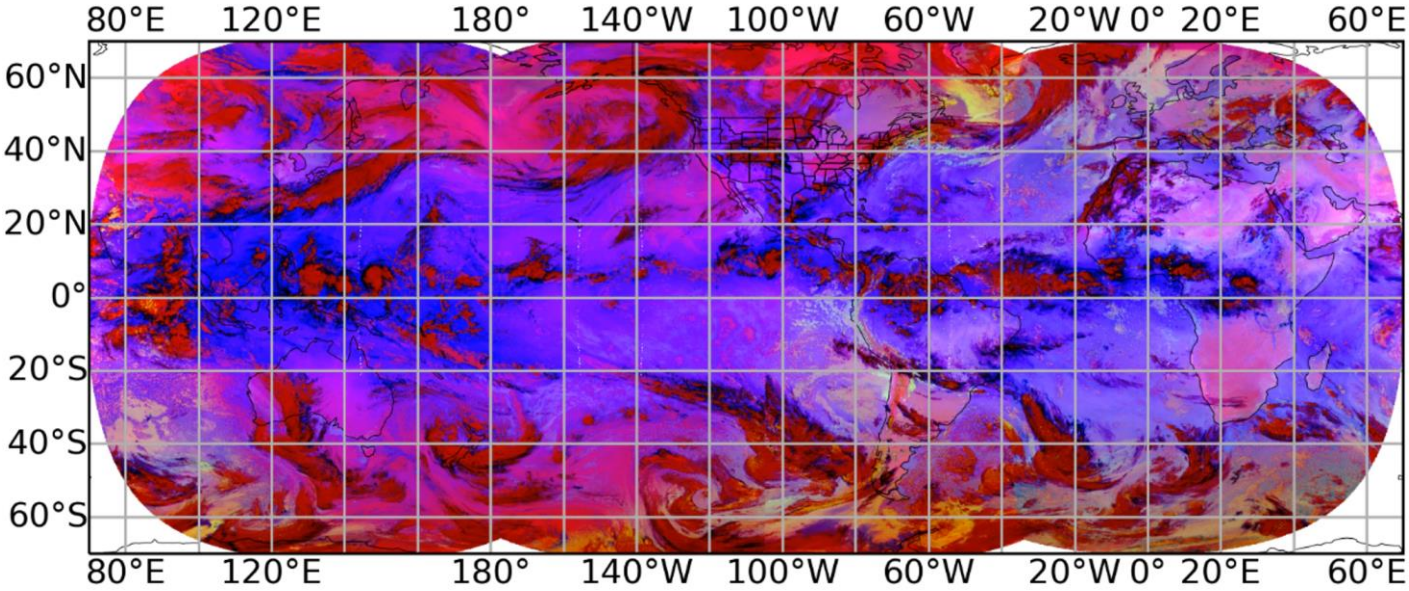
Limb-corrected



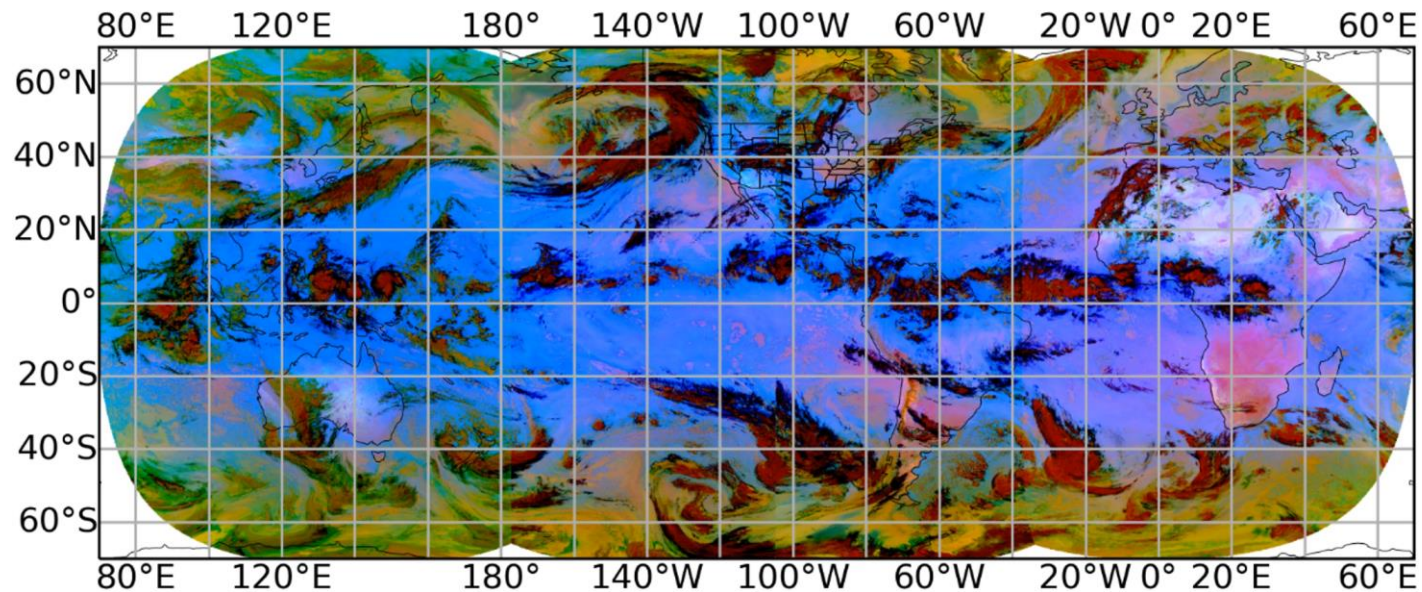
Uncorrected



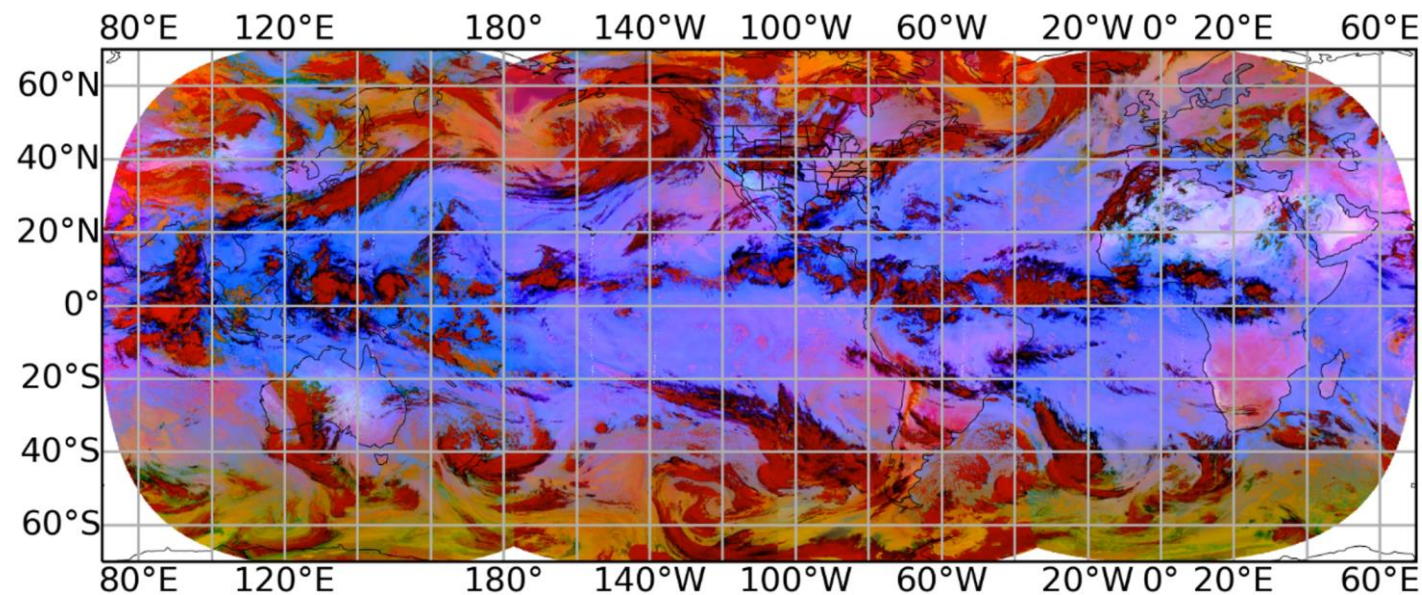
Limb-corrected



Uncorrected



Limb-corrected



- The use of RGB imagery on a global basis is not without limitations due to the impact of limb-effects at high viewing angles and subtle spectral channel differences between satellite sensors.
- Limb correction coefficients were derived largely following the methodology of Elmer et al. (2016, 2019) with a couple of key improvements to better capture temporal and spatial variability. Using a multi-year set of global model atmospheric profiles and a radiative transfer model statistical relationships between the satellite viewing zenith angle and brightness temperature were derived for geostationary sensors.
- Comparable channels from different sensors are intercalibrated by comparing infrared brightness temperatures of the reference sensor over cloud-free ocean scenes at shared near-nadir points for all other sensors, with observations separated in time by less than 10 minutes
- Limb correction reduces limb effects at 85° viewing zenith angle by 10-20 K for all bands (3.9 to 13.3 μm).
- Examples show the improved ability to track features such as cyclones, cloud features, and dust across satellite field on views without limb-effects or spectral differences impeding interpretation



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